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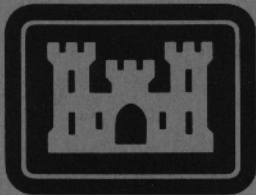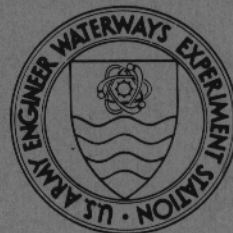
DREDGED MATERIAL RESEARCH PROGRAM

GUIDELINES FOR DESIGNING, OPERATING, AND MANAGING DREDGED MATERIAL CONTAINMENT AREAS

December 1978 (Reprinted January 1987)
Final Report

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Guidelines are presented for designing, operating, and managing dredged material containment areas to meet required effluent solids standards and to provide adequate storage volume. The guidelines are equally applicable to design of new containment areas and to evaluation of existing sites. Field investigations necessary to provide data for containment area design are described to include channel sediment investigations and foundation

(Continued)

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20.   ABSTRACT (Continued).

investigations at the containment area. Sample type and location, sampling equipment, and sample preservation techniques are included.

Laboratory testing procedures required to obtain data for sediment characterization, containment area design, and estimates of long-term storage capacity are given. Sediment characterization tests include salinity determination of near-bottom water and natural water content, Atterberg limits, organic content, specific gravity, and grain size analysis of the sediments. Sedimentation tests performed in an 8-in.-diam column are used to define settling behavior within the dredged material containment area. Procedures for both flocculent settling tests, generally applicable to freshwater sediments, and zone settling tests, generally applicable to saltwater sediments, are described. Results of conventional consolidation tests are used to estimate settlements due to self-weight consolidation of newly placed dredged material and consolidation of compressible foundation soils.

Procedures are given for containment area design for retention of suspended solids based on solids removal through gravity sedimentation. Separate design procedures for freshwater and saltwater sediments provide for determination of the respective surface area or detention time required to accommodate continuous dredged material disposal. Procedures are also given for estimation of the storage volume required for a single disposal activity and the corresponding ponding depths, freeboard requirements, and dike heights. Factors influencing containment area hydraulic efficiency are evaluated to include effects of short-circuiting, ponding depth, spur dikes, weir placement, and containment area shape.

Guidelines for estimation of gains in long-term storage capacity due to settlements within the containment area are presented. The guidelines are based on conventional consolidation theory modified to consider self-weight consolidation behavior of newly placed dredged material. The effects of foundation consolidation, time-rate of consolidation, and placement of sequential lifts of dredged material are also described.

Design and operational procedures for weirs are presented based on providing the capability of selective withdrawal of the clarified upper layer of ponded water. Weir design guidelines allow evaluation of the trade-off involved between the two most important weir design parameters, ponding depth and effective weir length. Operational procedures for weirs are outlined to include weir boarding, maintenance of adequate ponding depth, use of static head and depth of flow over the weir as operating parameters, and weir operation for undersized basins and for decanting surface water.

Containment area management activities are described which may be considered as possibilities for improving efficiency and prolonging the service life of containment areas. Separate activities may be performed before, during, and following the dredging operation and include site preparation, removal of existing dredged material for construction programs, surface water management, suspended solids monitoring, inlet and weir management, thin-lift placement, separation of coarse material, dredged material dewatering, and disposal area reuse management.

Summaries of research pertinent to designing, operating, and managing dredged material containment areas and example calculations are included in appendices to the main text.

SUMMARY

The purpose of this report is to provide guidelines for designing, operating, and managing dredged material containment areas to provide adequate storage volume and to meet required effluent suspended solids standards.

Field investigations are required to determine properties of the sediments to be dredged. Grab samples taken at the sediment surface are sufficient for most maintenance projects. Foundation conditions at the containment area must also be determined using conventional soil sampling techniques if estimates of settlement are required.

Laboratory tests necessary to characterize channel sediments include salinity of near-bottom water, natural water content, Atterberg limits, organic content, specific gravity, and grain size analysis. Sedimentation tests performed in an 8-in.-diam column are satisfactory for defining dredged material settling behavior within the containment area. Settling behavior in a freshwater environment is best described by a flocculent settling test, while behavior in a saltwater environment is best described by a zone settling test. The same settling column can be used for both tests with minor procedural changes. Conventional consolidation tests are adequate for determining consolidation properties of dredged material and foundation soils.

Containment area design for meeting effluent suspended solids criteria is based on determination of a surface area or detention time required to accommodate a continuous dredged material disposal operation. The designs call for suspended solids removal by the process of gravity sedimentation allowing discharge of carrier water from the containment area. Suspended solids removal efficiency for freshwater sediments depends on the ponding depth as well as the properties of the particles. The saltwater design procedure provides suspended solids removal to levels of 1 to 2 g/ℓ.

Required storage capacity to accommodate dredged material is estimated based on correlation of in situ sediment void ratios with containment area void ratios at completion of dredging; these are determined

from the sedimentation tests. Gains in storage capacity through settlement of dredged material and foundation soils can be estimated using conventional settlement analysis based on consolidation test data. Use of available computer models is recommended for cases involving repetitive disposal operations and/or intermittent dewatering or removal of material.

Ponding depths should be as great as possible to provide longer detention times and reduce the effects of short-circuiting. A minimum ponding depth of 2 ft is recommended for sedimentation of solids during a continuous disposal activity. Short-circuiting and dead zones can be reduced by judicious placement of weirs or use of multiple weirs. The hydraulic efficiency of containment areas is greatly influenced by length-to-width ratio, with greater length-to-width ratios being better. Spur dikes may be used to increase the length-to-width ratio. Spur dikes should be approximately three fourths the length of the parallel side. One or two spur dikes are usually sufficient and three or four should be the maximum number used.

Ponding depth and effective weir length, the minimum width over which flow must pass, are the two most important parameters in weir design. Properly designed weirs allow selective withdrawal of the clarified upper layer of ponded water. Adequate ponding depth during the dredging operation can be maintained by controlling the weir crest elevation. The weir should be boarded to provide the greatest possible ponding depth to ensure the maximum possible efficiency. Static head or depth of flow over the weir may be used as an operating parameter to control an intermittent disposal operation if effluent suspended solids concentrations are unacceptable.

Various containment area management strategies may be used to prolong containment area service life and increase efficiency. Use of existing dredged material should be considered for dike raising or other construction to provide additional storage capacity. During the disposal operation, surface water should be managed to provide maximum ponding and then removed quickly following the disposal operation to initiate drying.

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Suspended solids should be periodically monitored during the disposal operation to ensure that effluents remain within acceptable limits. Dredged material should be placed in as thin a lift as possible to enhance natural drying and potential gains in capacity through active dewatering and containment area reuse management activities.

PREFACE

This report synthesizes results of the Dredged Material Research Program (DMRP) pertinent to designing, operating, and managing dredged material containment areas. The DMRP was sponsored by the Office, Chief of Engineers, U. S. Army, and was assigned to the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES).

This study was conducted under Task 2C, Containment Area Operations (Mr. Newton C. Baker, Manager), of the Disposal Operations Project (Mr. Charles C. Calhoun, Jr., Manager). The study was conducted by the Water Resources Engineering Group (WREG) of the Environmental Engineering Division (EED), EL, under the general supervision of Dr. John Harrison, Chief, EL; Dr. Roger T. Saucier, Special Assistant, EL; and Mr. A. J. Green, Chief, EED. This report was written by Mr. Michael R. Palermo, WREG; Dr. Raymond L. Montgomery, Chief, WREG; and Ms. Marian E. Poindexter, WREG.

This report is also being published as Engineer Manual 1110-2-5006.

Director of WES during the study was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres (U. S. survey)	4046.856	square metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
gallons (U. S. liquid)	3.785412	litres
gallons (U. S. liquid) per minute	3.785412	litres per minute
inches	2.54	centimetres
miles (U. S. statute)	1.609344	kilometres
ounces (U. S. fluid)	29.57353	cubic centimetres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per hour-square foot	0.04214011	kilograms per hour-square metre
square feet	0.09290304	square metres
square inches	6.4516	square centimetres
tons (2000 lb force) per square foot	95.76052	kilopascals

GUIDELINES FOR DESIGNING, OPERATING, AND MANAGING

DREDGED MATERIAL CONTAINMENT AREAS

PART I: INTRODUCTION

Background

1. The purpose of this report is to provide guidelines for designing, operating, and managing dredged material containment areas to provide maximum storage volume and to meet required effluent solids standards. The guidelines presented are applicable to design of new containment areas and evaluation of existing sites and include data collection and sampling requirements, description of testing procedures, and design, operational, and management procedures.

2. Design procedures include the consideration of dredged material sedimentation and consolidation behavior and potential consolidation of foundation soils. Guidelines for containment area design for sedimentation were developed primarily for fine-grained material generated in maintenance dredging operations. Factors which improve containment area efficiency are presented and include weir design and location, effects of containment area size and shape, and use of interior spur dikes. Operational guidelines for containment areas during the dredging operation include weir operation and maintenance of adequate ponding depth. Guidelines for containment area management before, during, and after dredging operations to maximize efficiency and storage capacity are also presented.

3. This report does not contain information concerning treatment of contaminated effluents, design of containment area dikes, procedures for dredged material dewatering and densification, or disposal area reuse management practices. Information concerning these subjects is available in other U. S. Army Engineer Waterways Experiment Station (WES) Dredged Material Research Program (DMRP) reports.[1-4] Also, although not specifically covered in this report, guidelines have been developed by the DMRP for odor control, for mosquito and other insect

control, and for minimizing the adverse visual impact of disposal areas.[5-7] These factors should be considered in the earliest planning and design stages and carried through during construction and management phases.

Concepts of Containment Area Operation

4. Diked containment areas are used to retain dredged material solids while allowing the carrier water to be released from the containment area. The two objectives inherent in the design and operation of a containment area are: (a) to provide adequate storage capacity to meet dredging requirements and (b) to attain the highest possible efficiency in retaining solids during the dredging operation in order to meet effluent suspended solids requirements. These considerations are basically interrelated and depend upon effective design, operation, and management of the containment area.

5. The major components of a dredged material containment area are shown schematically in Figure 1. A tract of land is surrounded by dikes to form a confined surface area, and the dredged channel sediments are then pumped into this area hydraulically. The influent dredged material slurry can be characterized by suspended solids concentration,* particle gradation, type of carrier water (fresh or saline), and rate of inflow.

6. In some dredging operations, especially in the case of new work dredging, sand, clay balls, and/or gravel may be present. This coarse material (more than half >No. 40 sieve) rapidly falls out of suspension near the dredge inlet pipe forming a mound. The fine-grained material (more than half <No. 40 sieve) continues to flow through the containment area with most of the solids settling out of suspension, thereby occupying a given storage volume. The fine-grained dredged material is usually rather homogeneous and is easily characterized.

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* Procedures for determining and reporting suspended solids concentrations are presented in Appendix A.

PLAN

CROSS SECTION
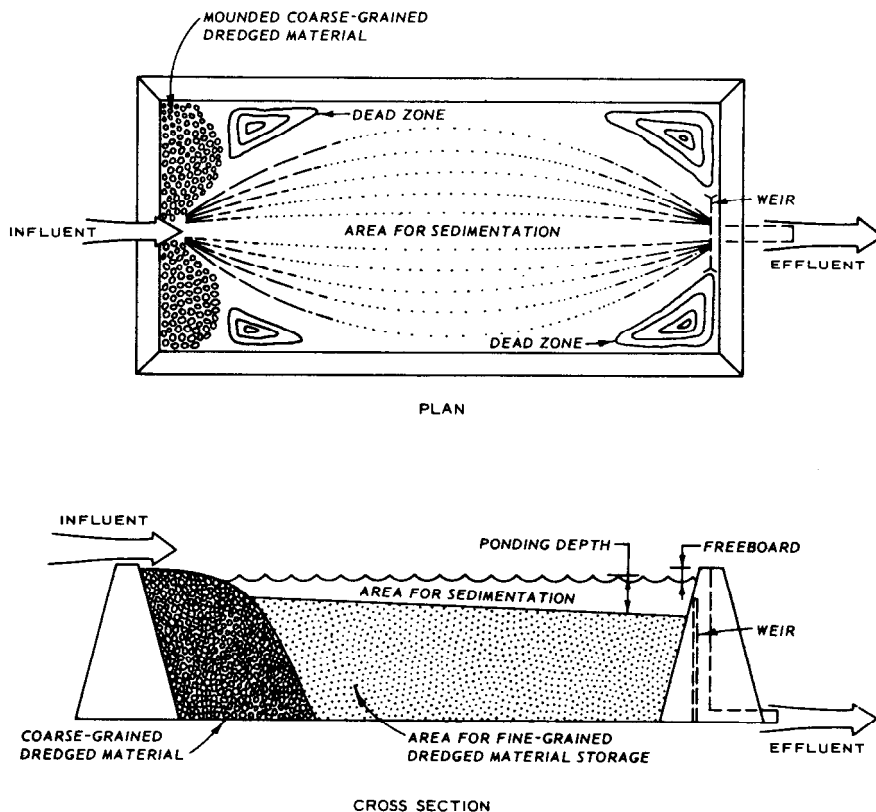
Figure 1. Conceptual diagram of a dredged material containment area (from Montgomery[8])

7. The clarified water is discharged from the containment area over a weir. This effluent may be characterized by its suspended solids concentration and rate of outflow. Effluent flow rate is approximately equal to influent flow rate for continuously operating disposal areas. Flow over the weir is controlled by the static head and the effective weir length provided. To promote effective sedimentation, ponded water is maintained in the area; the depth of water is controlled by the elevation of the weir crest. The thickness of the dredged material layer increases with time until the dredging operation is completed. Minimum freeboard requirements and mounding of coarse-grained material result in a ponded surface area smaller than the total surface area enclosed by the dikes. Dead spots in corners and other hydraulically inactive zones reduce the effective surface area, where sedimentation takes place, to considerably less than the ponded surface area.[9]

8. Field investigations are necessary to provide data for containment area design. The channel must be surveyed to determine the volume of material to be dredged, and channel sediments must be sampled to obtain material for laboratory tests. The foundation soils within the proposed containment area must be sampled to obtain soil for laboratory testing so that potential settlement, an important parameter in long-term storage capacity estimates, can be determined. This Part of the report describes field investigations required to obtain the necessary samples for laboratory testing. Summaries of sampling, testing, and data requirements are given in Appendix B. The methods in common use for determining volumes of channel sediment to be dredged are well known and do not warrant discussion here.

Channel Sediment Investigations

Sample type and location

9. Samples of the channel sediments to be dredged are required for adequate characterization of the material and for use in sedimentation and consolidation testing. The level of effort required for channel sediment sampling is highly project-dependent. In the case of routine maintenance work, data from prior samplings and experience with similar material may be available, and the scope of field investigations may be reduced. For unusual maintenance projects or new work projects, more extensive field investigations will be required.

10. For maintenance work, channel investigations may be based on grab samples of sediment. Since bottom sediments are in an essentially unconsolidated state, grab samples are satisfactory for sediment characterization purposes and are easy and inexpensive to obtain. Grab sampling may indicate relatively homogeneous sediment composition, segregated pockets of coarse- and fine-grained sediment, and/or mixtures. If segregated pockets are present, samples should be taken at a sufficient number of locations in the channel to adequately define spatial variations in the sediment character. In any case, results of grab

sampling must allow estimation of the relative proportions of coarse-
and fine-grained sediments present. Caution should be exercised in in-
terpreting conditions indicated by grab samples since sediment surface
samples do not indicate variation in sediment character with depth.
For more detailed information, additional samples may be taken using
conventional boring techniques.

11. Water samples should be taken at several locations near the
sediment-water interface in the area to be dredged. Subsequent salinity
tests on these samples indicate whether the dredging will be done in a
freshwater or saltwater environment. Potential changes in salinity due
to tides or seasonal flooding should also be considered.
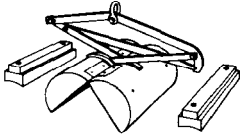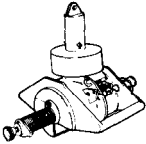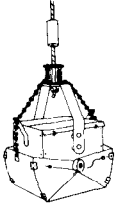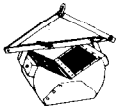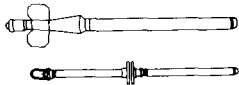
12. Samples of sediments taken by conventional boring techniques
are normally required only in the case of new work dredging. Based on
information gained from initial grab sampling, locations for borings
should be selected. Samples should be taken from within the major zones
of spatial variation in sediment type or along the proposed channel
center line at constant spacing to define stratification within the
material to be dredged and to obtain representative samples. Borings
should be advanced to the full depth of anticipated dredging if possi-
ble. This is normally done on a routine basis for new work projects to
indicate type of material to be dredged and the degree of dredging
difficulty since this information is required for the dredging con-
tractor to use as a basis for bidding on the project.

13. Sediment sampling equipment and procedures are described in
another DMRP report.[10] Pertinent information regarding sediment samplers
is also summarized in Table 1. Grab samplers as described in Table 1
will allow retrieval of sufficient amounts of sediment needed to per-
form characterization tests and sedimentation and consolidation tests,
if required.

Sample quantity

14. The quantity of sediment samples to be collected should be
determined by the designer based on the requirements for the laboratory
tests to be performed. A quantity of sediment sufficient to perform
the necessary characterization tests and to provide some material for

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Table 1

Summary of Sediment Sampling Equipment

Sampler		Weight	Remarks
Peterson		39-93 lb	Samples 144-in.^{2} area to a depth of up to 12 in., depending on sediment texture
Shipek		150 lb	Samples 64-in.^{2} area to a depth of approximately 4 in.
Ekman		9 lb	Suitable only for very soft sediments
Ponar		45-60 lb	Samples 81-in.^{2} area to a depth of less than 12 in. Ineffective in hard clay
Drag bucket		Varies	Skims an irregular slice sediment surface. Available in assorted sizes and shapes
Phlegar tube		Variable 17-77 lb; fixed in excess of 90 lb	Shallow core samples may be obtained by self-weight penetration and/ or pushing from boat. Depth of penetration dependent on weight and sediment texture
Conventional soil samplers			Conventional soil samplers may be employed using barge- or boat-mounted drilling equipment. Core samples attainable to full depth of dredging

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the column settling tests should be collected from each established sampling point. It is recommended that at least 5 gal* of sediment be collected at each sampling station. Five-gallon containers are generally recommended for collecting the grab samples. Since most sampling will be performed from small motorboats, containers of this size are about the largest that can be handled efficiently.

15. A smaller sample of sediment should be collected from each fine-grained grab sample and placed in a small (about 8-oz) watertight jar for water content and specific gravity tests. Care should be taken to collect small sediment samples that appear to be most representative of the sediment sample as a whole.

16. After the characterization tests have been performed on grab samples from each sampling point, samples can be combined to meet requirements for the settling tests. Approximately 15 gal of channel sediment is required to perform the column settling tests described in Part III and outlined in detail in Appendix A.

Sample preservation

17. The laboratory tests outlined in this report do not require sophisticated sample preservation measures. There are two requirements:

<u>a</u>. Collect the samples in airtight and watertight containers.

<u>b</u>. Place the samples in a cold room (6 to 8°C) within 24 hours after sampling until the organic content of the samples can be determined. If the organic content is above 10 percent, the samples should remain in the cold room until testing is complete; otherwise, the samples need not be stored in the cold room. The in situ water content of the small samples must be maintained. These samples should not be allowed to drain nor should additional water be added when they are placed into the containers.

18. All sample containers should be clearly identified with labels, and the sample crew should keep a field log of the sampling activity. Laboratory testing should be accomplished on the samples as soon as practicable after sampling.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 11. Metric (SI) units are used in this report when consistent with standard usage.

Containment Area Investigations

19. Field investigations must be performed at the containment area to define foundation conditions and to obtain samples for laboratory testing if estimates of long-term storage capacity are required. The extent of required field investigations is dependent upon project size and upon foundation conditions at the site. It is particularly important to define foundation conditions including depth, thickness, extent, and composition of foundation strata and to obtain undisturbed samples of compressible foundation soils and any previously placed dredged material. For new containment areas, the field investigations required for estimating long-term storage capacity should be planned and accomplished along with those required for the engineering design of the retaining dikes.

20. For existing containment areas, the foundation conditions may have been defined by previous subsurface investigations made in connection with dike construction. However, previous investigations may not have included sampling of compressible soils for consolidation tests; in most cases, suitable samples of any previously placed dredged material are not available. Field investigations must therefore be tailored to provide those items of information not already available.

21. Undisturbed samples of the compressible foundation soils can be obtained using conventional soil sampling techniques and equipment. If dredged material has previously been placed within the containment area, undisturbed samples must be obtained from borings taken within the containment area but not through existing dikes. The major problem in sampling existing containment areas is that the surface crust will not normally support conventional drilling equipment, and personnel sampling in these areas must use caution. Below the surface crust, fine-grained dredged material is usually soft, and equipment will sink rapidly if it breaks through the firmer surface. Lightweight drilling equipment, supported by mats, will normally be required if crust thickness is not well developed. In some cases, sampling may be accomplished manually, if sufficient dried surface crust has formed to support crew and equipment. More detailed information regarding equipment use in

containment areas may be found in another DMRP report.[11]

22. Water table conditions within the containment area must be determined in order to estimate loadings caused by placement of dredged material. This information must be obtained by means of piezometers which may also be used for measurement of groundwater conditions during the service life of the area. Other desired instrumentation such as settlement plates may also be installed within the containment area for monitoring various parameters.

23. Additional information regarding conventional sampling techniques and equipment and developing field exploration programs is given in Engineer Manual EM 1110-2-1907[12] and in another DMRP report.[2] Procedures for installation of piezometers and other related instrumentation are given in EM 1110-2-1908.[13]

24. Laboratory tests are required primarily to provide data for sediment characterization, containment area design, and long-term storage capacity estimates. The laboratory tests and procedures described in this Part are essentially standard tests and generally follow procedures found in Standard Methods[14] and EM 1110-2-1906.[15] Other nonstandard tests not covered in the above references are outlined in detail in Appendix A. A flow chart illustrating the complete laboratory testing program for sediment samples is shown in Figure 2. Sediment character and requirements for sedimentation data and for long-term storage capacity estimates will dictate which laboratory tests are required. Not all laboratory tests indicated in Figure 2 are required for every application. The testing program for foundation materials includes only standard soil classification and consolidation testing and therefore is not illustrated by a flow chart. A summary of design data requirements is given in Appendix B.

25. The required magnitude of the laboratory testing program is highly project-dependent. Fewer tests are usually required when dealing with a relatively homogeneous material and/or when data are available from previous tests and experience, as is frequently the case in maintenance work. For unusual maintenance projects where considerable variation in sediment properties is apparent from samples or for new work projects, more extensive laboratory testing programs are required. Laboratory tests should always be performed on representative samples selected using sound engineering judgment.

Sediment Characterization Tests

26. A number of sediment characterization tests are required before settling tests can be performed. Visual classification will establish whether the sediment sample is predominantly fine-grained (more than half <No. 40 sieve) or coarse-grained (more than half >No. 40 sieve). Tests required on fine-grained sediments include natural water content, Atterberg limits, organic content, and specific gravity. The

SEDIMENT
SAMPLE *

VISUAL
CLASSIFICATION → CLEAN SANDS

FINE-GRAINED
(< 40 SIEVE) ← SEPARATION
(40 SIEVE) → COARSE-GRAINED
(> 40 SIEVE)

SPECIFIC
GRAVITY

PLASTICITY
ANALYSES

GRAIN SIZE
ANALYSES

ORGANIC
CONTENT

CLASSIFICATION

(< 40 SIEVE)

YES ← FRESHWATER
SEDIMENTS +
? → NO

FLOCCULENT
SETTLING
TESTS ˣ

ZONE
SETTLING
TESTS ˣ

SEDIMENTATION
PROPERTIES
DATA

LONG-TERM
SIZING
REQUIRED
? → NO

DESIGN
CONTAINMENT
AREA

YES

CONSOLIDATION
TEST

DESIGN
CONTAINMENT
AREA

NOTES:

* NATURAL WATER CONTENTS SHOULD
BE DETERMINED ON FINE-GRAINED
SEDIMENTS.

+ IN AN ESTUARINE SYSTEM WATER
SAMPLES TAKEN FROM THE BOTTOM
OF THE CHANNEL SHOULD BE TESTED
TO DETERMINE SALINITY.

ˣ MAY BE PERFORMED ON COMPOSITE
SAMPLES.

Figure 2. Flow chart depicting laboratory testing
program for sediment samples (from Montgomery[8])

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coarse-grained sediments require only grain size analyses. Results of these tests can be used to classify the sediments according to the Unified Soil Classification System (USCS).[16]

Salinity

27. Near-bottom water samples from the area to be dredged should be tested for salinity to determine whether the sediment source should be classified as freshwater or saltwater. This classification will determine the type settling tests required and influence the other characterization tests. If the water classifies as saline (>3 ppt), ambient water gathered during the field investigation or reconstituted salt water should be used when additional water is required in all subsequent characterization tests and in the sedimentation tests.

Water content

28. Water content is an important factor used in sizing dredged material containment areas. Water content determinations should be made on representative samples from borings or grab samples of fine-grained sediment obtained in the field investigation phase. In the case of mixtures of coarse- and fine-grained samples, the water content of the sample should be determined prior to separation on the No. 40 sieve as described below. The detailed test procedure for determining the water content is found in Appendix I of EM 1110-2-1906.[15] The water content is expressed on a dry weight basis as follows:

$$w = \frac{W_W}{W_S} \times 100\%$$ (1)

where

w = water content, percent*

W_W = weight of water in sample, g

W_S = weight of solids in sample, g

Sample separation

29. It is emphasized that sediment character as determined from

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* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix E).

in situ samples is not indicative of dredged material behavior after dredging since the fine-grained (<No. 40 sieve) fraction will undergo natural segregation within the containment area and will behave independently of the coarse-grained (>No. 40 sieve) fraction. Therefore, the relative percentage (dry weight basis) of coarse- and fine-grained material should be determined by separation of a small portion of the sample using a No. 40 sieve and following procedures generally described in EM 1110-2-1906.[15]

30. If the coarse-grained fraction is less than 10 percent by dry weight, the sediment sample is considered to be fine grained and is treated as though all the material passed the No. 40 sieve; separation for further characterization tests is not required. If the coarse-grained fraction is greater than 10 percent by dry weight, the entire sample should be separated on the No. 40 sieve prior to further testing.

Grain size analyses

31. Grain size analyses as described below should be performed on coarse-grained samples or on the coarse-grained fraction of samples that are mixtures of coarse- and fine-grained material. These analyses are used to classify the coarse-grained portion of the sediments. The fine-grained material (passing the No. 40 sieve) should be used in the other characterization tests, sedimentation tests, and consolidation tests if required. Grain size analyses should follow the procedures contained in EM 1110-2-1906.[15] Hydrometer analyses can be used to define the grain size distribution of the fine-grained fraction if desired.

Plasticity analyses

32. In order to evaluate the plasticity of fine-grained samples of sediment, the Atterberg liquid limit (LL) and plastic limit (PL) must be determined. The LL is that water content above which the material is said to be in a semiliquid state and below which the material is in a plastic state. Similarly, the water content which defines the lower limit of the plastic state and the upper limit of the semisolid state is termed the PL. The plasticity index (PI), defined as the numerical difference between the LL and the PL, is used to express the plasticity of the sediment. Plasticity analyses should be performed on the

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separated fine-grained fraction (<No. 40 sieve) of sediment samples. A detailed explanantion of the LL and PL test procedures and apparatus can be found in Appendix III of EM 1110-2-1906.[15]

Organic content

33. For classification purposes, the organic content generally need not be quantified, but rather a knowledge of whether significant organic matter is present is required. The recommended test procedure to determine the organic content is presented in Appendix A.

Specific gravity

34. Values for the specific gravity of solids for fine-grained sediments and dredged material are required for determining void ratios, conducting hydrometer analyses, and consolidation testing. Procedures for conducting the specific gravity test are given in Appendix IV of EM 1110-2-1906.[15]

USCS classification

35. When classifying sediment samples, the fine-grained portion which passes the No. 40 sieve should be classified separately from the coarse-grained portion retained on the No. 40 sieve, regardless of which fraction comprises the greatest percentage by weight. Additional information regarding the USCS classification may be found in WES Technical Memorandum No. 3-357.[16]

Sedimentation Tests

36. Sedimentation, as applied to dredged material disposal activities, refers to those operations in which the dredged material slurry is separated into more clarified water and a more concentrated slurry. Laboratory sedimentation tests must provide data for designing the containment area to meet effluent suspended solids criteria and to provide adequate storage capacity for the dredged solids. These tests are based on the gravity separation of solid particles from the transporting water.

37. The sedimentation process can be categorized according to three basic classifications: (a) discrete settling where the particle maintains its individuality and does not change in size, shape, or

density during the settling process; (b) flocculent settling where particles agglomerate during the settling period with a change in physical properties and settling rate; (c) zone settling where the flocculent suspension forms a lattice structure and settles as a mass, exhibiting a distinct interface during the settling process.

38. The important factors governing the sedimentation of dredged material solids are initial concentration of the slurry and flocculating properties of the solid particles. Because of the high influent solids concentration and the tendency of dredged material fine-grained particles to flocculate, either flocculent or zone settling behavior governs sedimentation in containment areas.[8] Discrete settling describes the sedimentation of sand particles and fine-grained sediments at concentrations much lower than those found in dredged material containment areas.

39. The objective of running settling tests on sediments to be dredged is to define, on a batch basis, settling behavior in a large-scale continuous flow dredged material containment area. The tests provide numerical values for the design criteria which can be projected to the size and design of the containment area. It is important that the sediment slurry tested have characteristics in the settling column similar to those it will have in the containment area. This becomes increasingly difficult as the sediment slurry becomes more flocculent and as concentrations increase.

40. Comparative laboratory and field studies indicate that the test procedures using the settling column shown in Figure 3 are satisfactory, with minor procedural changes, for both freshwater and saltwater sediments.[8] Sedimentation of freshwater sediments at slurry concentrations <100 g/ℓ can generally be characterized by flocculent settling properties. As slurry concentrations are increased, the sedimentation process may be characterized by zone settling properties. Salinity >3 ppt enhances the flocculation of dredged material particles. Therefore, the settling properties of saltwater dredged material can usually be characterized by zone settling tests.

41. Samples used to perform sedimentation tests should consist of fine-grained (<No. 40 sieve) material. If coarse-grained (>No. 40 sieve)
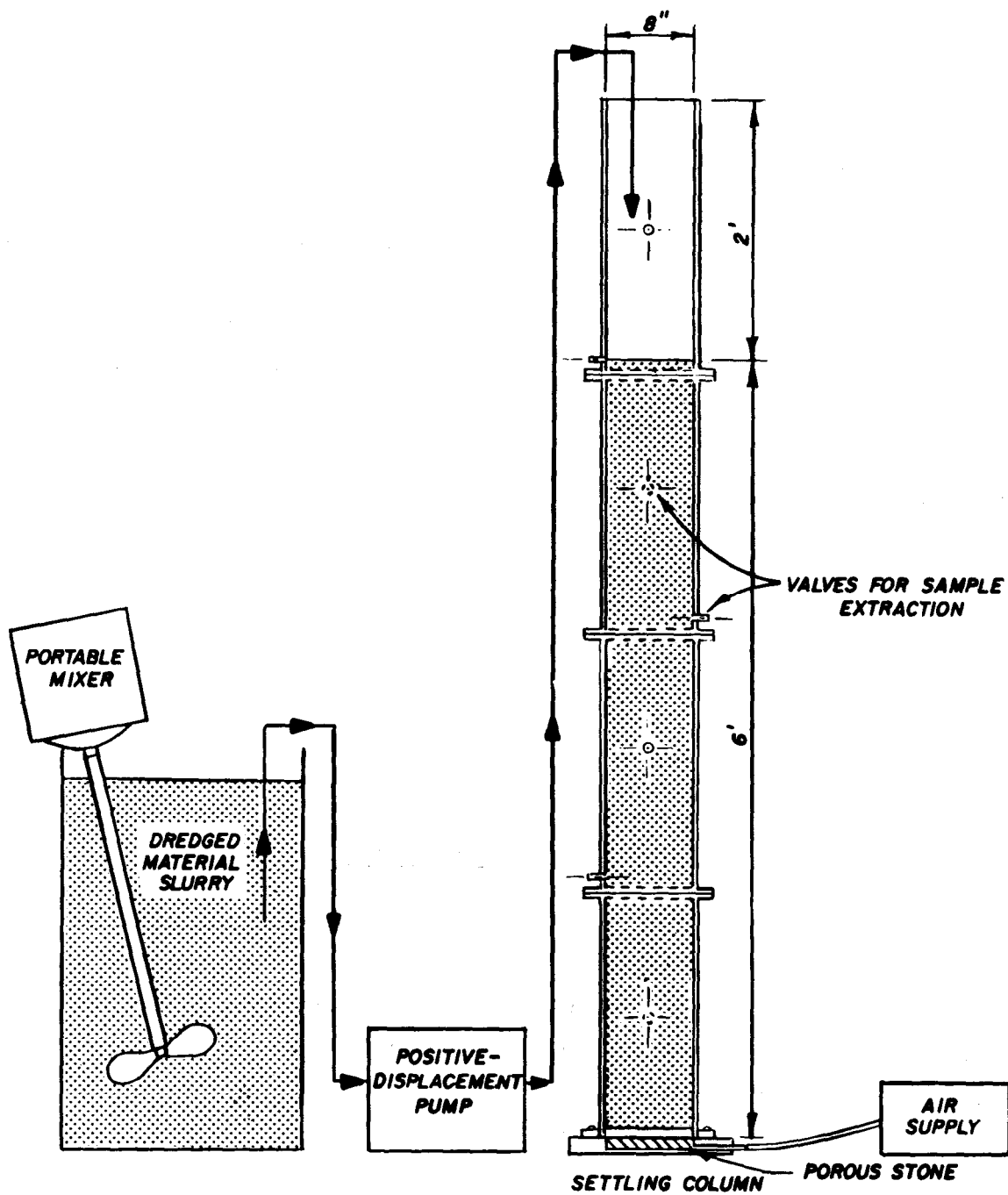
Figure 3.   Schematic of apparatus for settling tests
(from Montgomery[8])

material present in the sample is less than 10 percent (dry weight basis), separation is not required prior to sedimentation testing. A composite of several sediment samples may be used to perform the tests if this is thought to be more representative of the dredged material. Approximately 15 gal of sediment is usually required for the tests.

Flocculent settling test

42. The flocculent settling test consists of measuring the concentration of suspended solids at various depths and time intervals in a settling column. If an interface forms near the top of the settling column during the first day of the test, sedimentation is governed by zone settling, and that test procedure should be initiated. Detailed test procedures for the flocculent settling test are presented in Appendix A.

Zone settling test

43. The zone settling test consists of placing a slurry in a sedimentation column and reading and recording the fall of the liquid-solids interface with time. These data are plotted as depth to interface versus time. The slope of the constant settling zone of the curve is the zone settling velocity, which is a function of the initial test slurry concentration. Detailed test procedures for the zone settling test are presented in Appendix A.

Consolidation Testing

44. Determination of containment area long-term storage capacity requires estimates of settlement due to self-weight consolidation of newly placed dredged material and due to consolidation of compressible foundation soils. Consolidation test results must be obtained, including time-consolidation data, to estimate the average void ratios at completion of 100 percent primary consolidation.
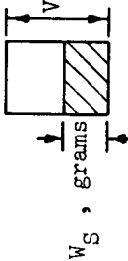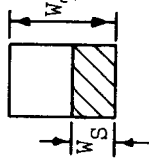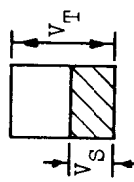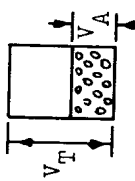
45. Consolidation tests for foundation soils should be performed as described in EM 1110-2-1906[15] with no modifications. The consolidation testing procedure for sediment samples generally follows that for the fixed ring test for conventional soils, but minor modifications are required.

46. Fixed ring consolidometers should be used for consolidation testing of sediment samples due to their fluidlike consistency. The only major modifications for the conventional fixed ring testing procedure concern the sample preparation and the method of loading. Detailed descriptions of test procedures are presented in Appendix A.

Solids Concentration

47. Determinations of solids concentrations are required for settling tests and for samples of containment area influent and effluent taken during the course of containment area management activities. Solids associated with dredged material disposal activities can be divided into total and suspended solids. In practice there has been confusion concerning the method of reporting suspended solids. The terms "concentration in grams per litre," "percent solids by weight," "percent solids by volume," and "percent solids by apparent volume" have been used. These methods of reporting suspended solids concentration are discussed and compared in Table 2. The relationship between percent solids by weight and concentration in grams per litre is illustrated in Figure 4. Suspended solids concentration in grams per litre is used throughout this report. Test procedures for determining suspended solids concentrations are presented in Appendix A.

Table 2

Methods of Reporting Suspended Solids

Method of Reporting Suspended Solids	Weight-Volume Relationship	Method of Computation	Remarks
		Preferred Method	
grams per litre or milligrams per litre	$V_T = 1$ litre $\quad W_S$, grams	$S = \dfrac{W_S}{V_T}$	Common method for reporting dissolved chemical concentrations. Best method for engineering purposes
		Other Methods	
percent by weight	$W_T \quad W_S$	$S = \dfrac{W_S}{W_T}\,100$	Easy to determine by laboratory test. Does not require value for specific gravity
percent by volume	$V_T \quad V_S$	$S = \dfrac{V_S}{V_T}\,100$	Easy to determine by laboratory test. Requires determination of percent by weight and value for specific gravity
percent by apparent volume	$V_A = V_S + V_I \quad V_T$	$S = \dfrac{V_A}{V_T}\,100$	Apparent volume determined by settled solids for a bottle or flask. No standardized procedure available. Void ratio of settled solids varies with type of sediment. Can lead to errors because of nonstandard test. Not recommended. Value is meaningless in engineering calculations

Note: W_S = ovendry weight of solid particles

V_T = total volume

W_T = total weight

V_S = volume of solid particles

V_A = apparent volume of settled solids

V_I = volume of interstitial water

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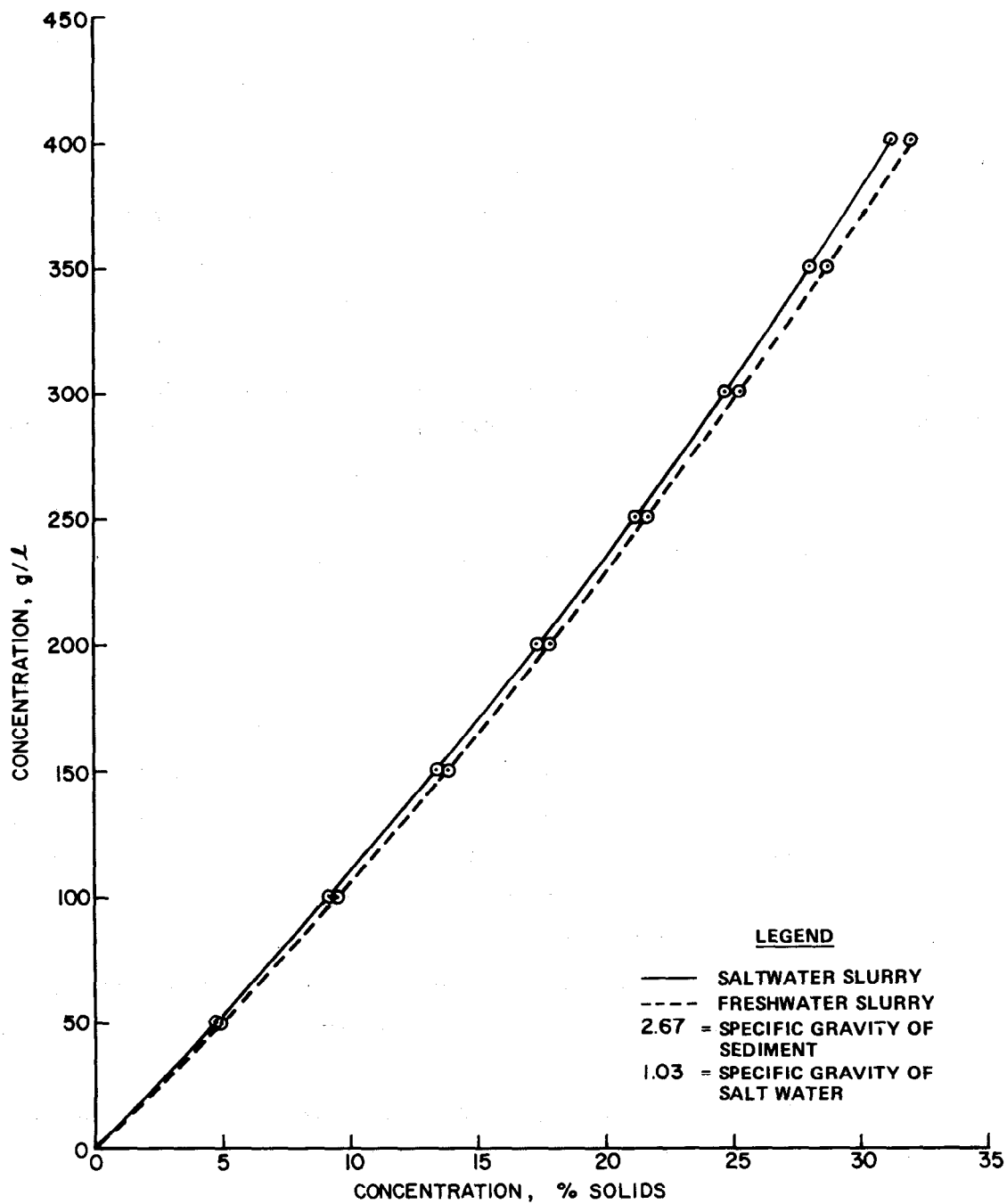
Figure 4. Relationship between concentration in percent solids by weight and in grams per litre (from Montgomery[8])

48. This Part of the report presents guidelines for designing a
new containment area for suspended solids retention and for evaluating
the suspended solids retention potential of an existing containment area.
The focus in this report is on fine-grained dredged material. Guidelines
presented here will provide the necessary guidance for designing a con-
tainment area for adequate area and volume for (a) clarification of the
transporting water and (b) containment of dredged solids for a particular
continuous dredged material disposal activity. The major objective is to
provide solids removal by the process of gravity sedimentation to a level
that permits discharge of the transporting water from the area. It is
recognized that the design procedures described in this Part are not
totally applicable to very large containment areas. Although ponding is
not feasible over the entire surface area of such sites, an adequate
ponding depth must be maintained over the design surface area as deter-
mined by the design procedures to assure adequate retention of solids.

49. The flow chart shown in Figure 5 illustrates the design pro-
cedures presented in the following paragraphs. A summary of design data
requirements is presented in Appendix B. The design procedures were
adapted from procedures used in water and wastewater treatment and are
based on field and laboratory investigations on sediments and dredged
material at several active dredged material containment areas.[8] Design
methods for saltwater and freshwater sediments are presented. Essen-
tially, the method for saltwater sediments is based on zone settling
properties, and the method for freshwater sediments is based on floccu-
lent settling properties.

50. The design procedures presented here are for gravity sedi-
mentation of dredged suspended solids. However, the process of gravity
sedimentation will not completely remove the suspended solids from the
containment area effluent since wind and other factors can resuspend
solids and increase effluent solids concentration. The sedimentation
process, with proper design and operation, will normally provide

ANALYZE AVAILABLE
PROJECT DATA

PLAN & PERFORM FIELD INVESTIGATIONS

PERFORM LABORATORY
CLASSIFICATION TESTS

FRESHWATER
FINE-GRAINED
SEDIMENTS
?

YES

NO

PLAN & PERFORM
FLOCCULENT &
ZONE SETTLING
TESTS

PLAN & PERFORM
ZONE SETTLING
TESTS

REDUCE AND
EVALUATE DATA

REDUCE AND
EVALUATE DATA

DETERMINE DETENTION
TIME REQUIRED FOR
SUSPENDED SOLIDS REMOVAL

DETERMINE AREA
REQUIRED FOR
SEDIMENTATION

COMPUTE VOLUME
REQUIRED FOR
CONTAINMENT OF
SOLIDS

ADD PONDING DEPTH
AND FREEBOARD

RECOMMEND CONTAINMENT
AREA DESIGN FOR
SUSPENDED SOLIDS RETENTION

Figure 5.   Flow chart of design procedure for
fine-grained sediments (from Montgomery[8])

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removal of fine-grained sediments down to a level of 1 to 2 g/ℓ in the effluent. If the required effluent standard is lower than this, the designer must provide for additional treatment of the effluent; e.g., flocculation or filtration. Information concerning treatment of containment area effluents is found in another DMRP synthesis report.[17]

Data Requirements

51. The data required to use the design guidelines are obtained from field investigations, laboratory testing, dredging equipment designs, and past experience in dredging and disposal activities.

Estimate in situ sediment volume

52. The initial step in any dredging activity is to estimate the in situ volume of sediment to be dredged. Sediment quantities are usually determined from channel surveys on a routine basis by Corps District personnel.

Determine physical characteristics of sediments

53. Field sampling should be accomplished as described in Part II, and sediment characterization should be accomplished according to the laboratory tests described in Part III. Adequate sample coverage is required to provide representative samples of the sediment. Also required are in situ water contents of the fine-grained maintenance sediments. Care must be taken in sampling to ensure that the water contents are representative of the in situ conditions. Water contents of representative samples w are used to determine the in situ void ratios e_i as follows:

$$e_i = \frac{wG_s}{S_D} \tag{2}$$

where

G_s = specific gravity of sediment solids

S_D = degree of saturation (equal to 100 percent for sediments)

A representative value from in situ void ratios is used later to estimate volume for the containment area. Grain size analyses are used to

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estimate the quantities of coarse- and fine-grained material in the sediment to be dredged.

Obtain and analyze proposed dredging and disposal data

54. The designer must obtain and analyze data concerning the dredged material disposal rate. For hydrualic pipeline dredges, the type and size of dredge(s) to be used, average distance to containment area from dredging activity, depth of dredging, and average solids concentration of dredged material when discharged into the containment area must be considered. If the size of the dredge to be used is not known, the largest dredge size that might be expected to perform the dredging should be assumed. The time required for the dredging can be estimated based on past experience. If no data on past experience are available, Figure 6, which shows the relationship among solids output, dredge size, and pipeline length for various dredging depths, should be used. It was developed from data provided for Ellicott dredges.[18] For hopper dredges, an equivalent disposal rate must be estimated based on hopper or barge pump-out rate and travel time involved.

55. Based on these data, the designer must estimate or determine containment area influent rate, influent suspended solids concentration, effluent rate (for weir sizing), effluent concentration allowed, and time required to complete the disposal activity. For hydraulic pipeline dredges, if no other data are available, an influent suspended solids concentration of 145 g/ℓ (13 percent by weight) should be used for design purposes. This value is based on a number of field investigations performed under DMRP research.[8]

Perform laboratory sedimentation tests

56. The guidelines for sedimentation tests are given in Appendix A. The designer must evaluate the results of salinity tests to determine whether the sediments to be dredged are freshwater or saltwater sediments. If salinity is above 3 ppt, the sediments are classified as saltwater sediments for the purpose of selecting the laboratory sedimentation test.
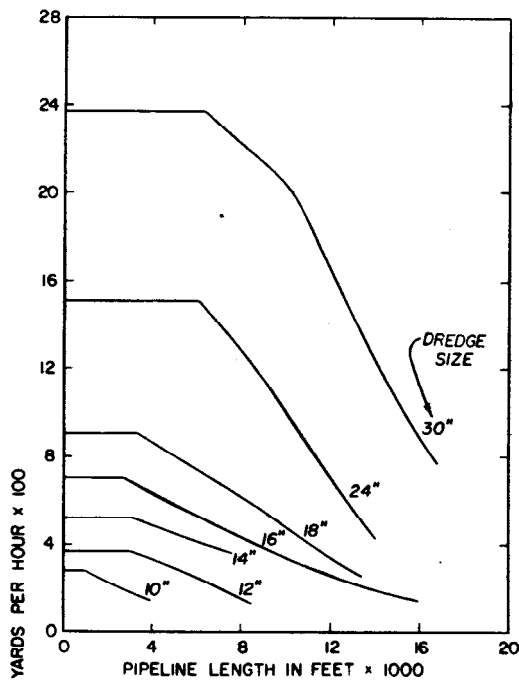
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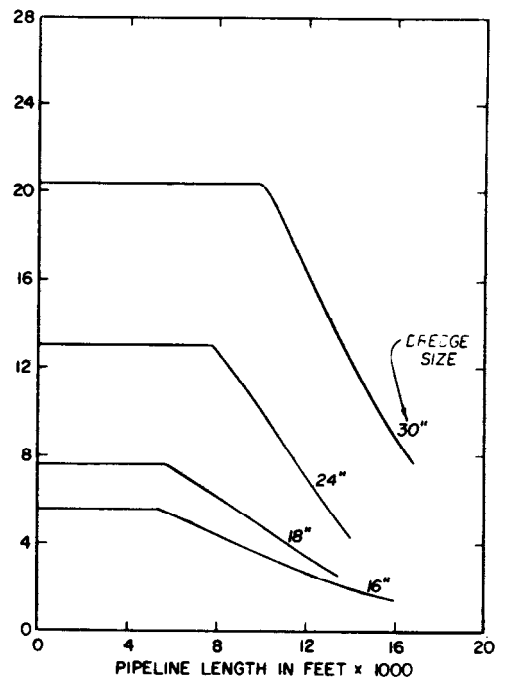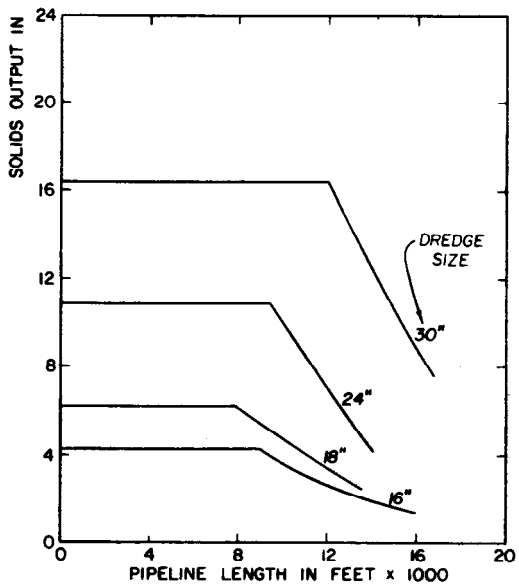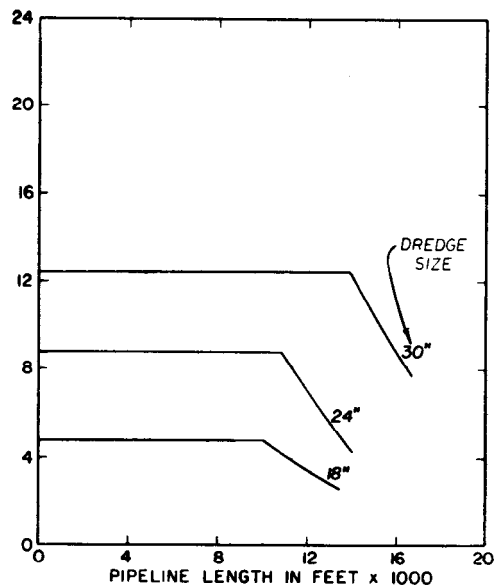
Figure 6.   Relationships among solids output, dredge size, and pipeline
length for various dredging depths (developed from data provided by
Turner[18])

57. The following method provides adequate designs for sedimentation of dredged material from a saltwater environment.[8] This method can also be used for freshwater dredged material if the laboratory settling tests indicate zone settling properties. An example of this design method is presented in Appendix C.

Analyze laboratory data

58. A series of zone settling tests must be conducted as detailed in Appendix A. The results of the settling tests are correlated to determine zone settling velocities at the various suspended solids concentrations. The procedure is as follows:

    a. Develop a settling curve for each test (see Figure A1).

    b. Calculate the zone settling velocity v_s as the slope of the constant settling zone (straight-line portion of curve). The velocity should be in feet per hour.

    c. Plot the v_s versus suspended solids concentration on a semilog plot as shown in Figure A2.

    d. Use the plot developed in c to develop a solids loading versus solids concentration curve as shown in Figure 7.

Compute design concentration

59. The design concentration C_d is defined as the average concentration of the dredged material in the containment area at the end of the disposal activity and is estimated from data obtained from the 15-day column settling tests described in Appendix A. The following steps can be used to estimate average containment area concentrations for each 15-day column settling test. It may be desirable to perform more than one 15-day test. If so, use an average of the values as the design concentration.

    a. Compute concentration versus time for the 15-day settling test. Assume zero solids in the water above the solids interface to simplify calculations.

    b. Plot concentration versus time on log-log paper as shown in Figure C12.

    c. Draw a straight line through the data points. This line should be drawn through the points representing the consolidation zone as shown in Figure A1.

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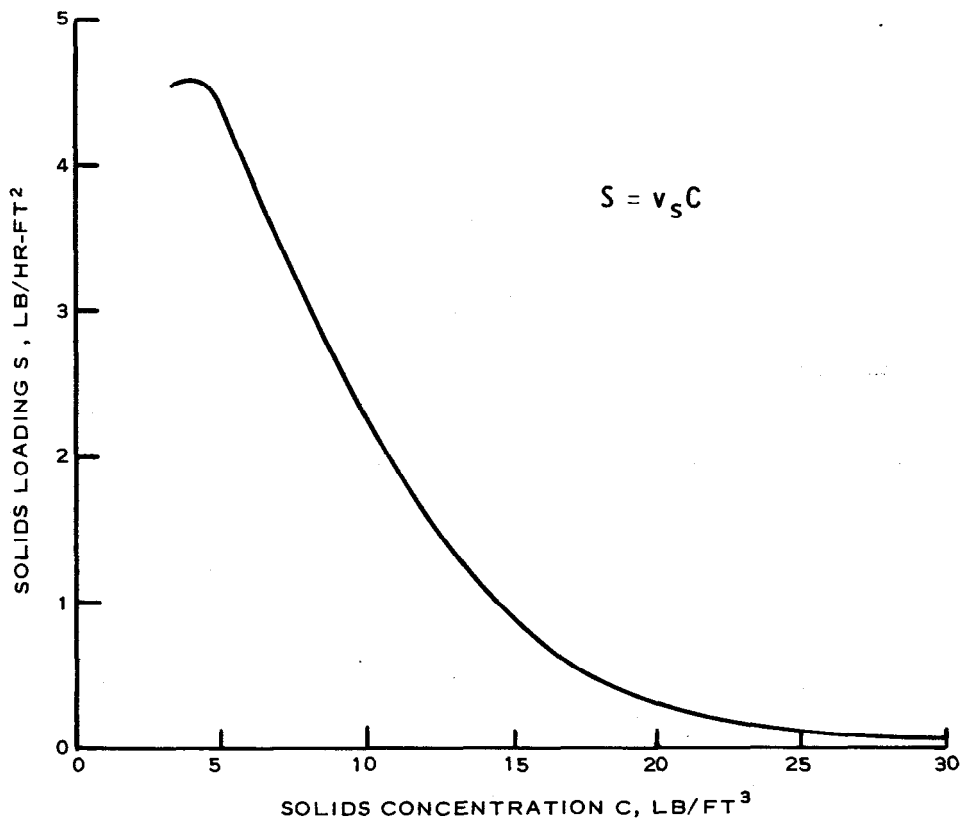
Figure 7. Typical solids loading curve for dredged material (from Montgomery[8])

    d. Estimate the time of dredging by dividing the dredge production rate into the volume of sediment to be dredged. Use Figure 6 for estimating the dredge production rate if no specific data are available from past dredging activities.

    e. Using the figure developed in steps b and c (see Appendix C), determine the concentration at time t equals one half the time required for the disposal activity determined in step d.

    f. Use the value computed in step e as the design solids concentration C_d .

Compute area required for sedimentation

60. Containment areas designed according to the following steps should provide removal of fine-grained sediments such that suspended solids levels in the effluent do not exceed 1 to 2 g/ℓ. The area required for the zone settling process to concentrate the dredged material to the design concentration is computed as follows:

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<u>a</u>. Use the design concentration and construct an opereting
line from the design solids concentration tangent to the
loading curve as shown in Figure 8. The design loading
is obtained on the y-axis as S_d .
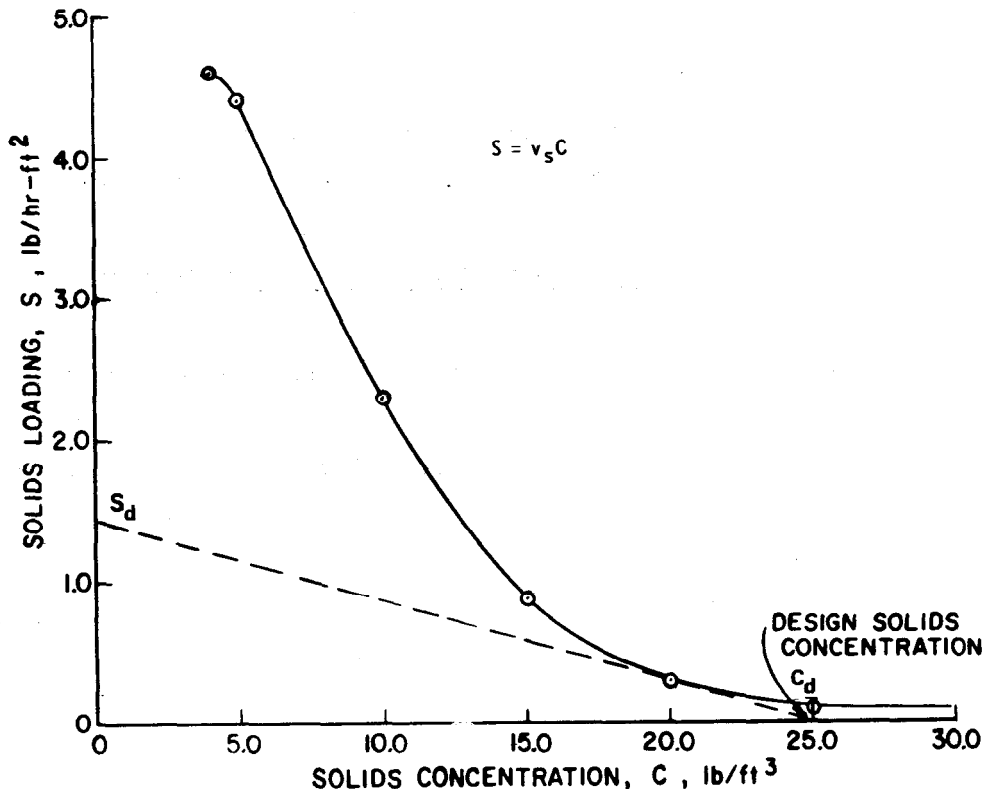
Figure 8. Solids loading curve showing design line
(from Montgomery[8])

<u>b</u>. Compute area requirements as

$$A = \frac{Q_i C_i}{S_d}$$ (3)

where

A = containment surface area requirement, ft^2

Q_i = influent rate, ft^3/hr ($Q_i = A_p V_d$; assume V_d
= 15 fps in absence of data and convert Q_i
calculated in cfs to ft^3/hr)

A_p = cross-sectional area of dredge pipeline, ft^2

V_d = velocity of dredge discharge, ft/sec

C_i = influent solids concentration, lb/ft^3 (use
145 g/ℓ or 9.2 lb/ft^3 if no data are available)

$$S_d = \text{design solids loading, lb/hr-ft}^2$$

c. Increase the area by a factor of 2.25 to compensate for containment area inefficiencies*

$$A_d = 2.25A \qquad\qquad (4)$$

where

A_d = design basin surface area, ft^2

A = area determined from Equation 3, ft^2

Design Method for Freshwater Sediments

61. Sediments dredged from a freshwater environment have been found to exhibit flocculent settling properties.[8] However, in some cases, the concentration of these sediments is sufficiently high that zone settling will occur. The method of settling can be determined from the laboratory tests.

62. Sediments in a dredged material containment area are comprised of a broad range of particle flocs of different sizes and surface characteristics. In the containment area, larger particle flocs settle at faster rates, thus overtaking finer flocs in their descent. This contact increases the floc sizes and enhances settling rates. The greater the ponding depth in the containment area, the greater is the opportunity for contact among sediments and flocs. Therefore, sedimentation of freshwater dredged sediments is dependent on the ponding depth as well as the properties of the particles.

63. Evaluation of the sedimentation characteristics of a freshwater sediment slurry is accomplished as discussed in Part III. The design steps are as follows (refer to Appendix C for example problems):

a. Step 1. Analyze laboratory data:

(1) Arrange the data from laboratory tests illustrated by Table C1 into the form shown in Table C2 (see Appendix C).

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* Additional information regarding containment area inefficiencies is found beginning in paragraph 70.

(2) Plot these data as shown in Figure 9. The percent
of initial concentration by weight for each depth and
time is given in Table C2. The solid curved lines
represent the concentration depth profile at various
times during settling (refer to Figure C1 for more
details). Numbers appearing along the horizontal
depth lines are used to indicate area boundaries.
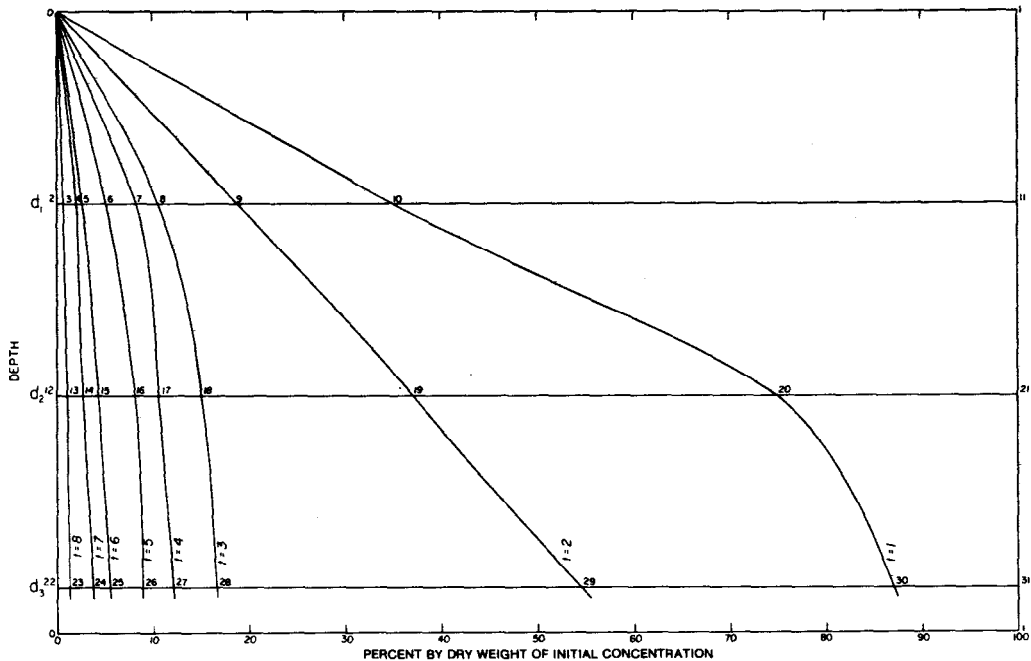
Figure 9. Removal of flocculating dredged material
particles (from Montgomery[8])

(3) Compute a design concentration using data from the
15-day zone settling test. Follow the procedure out-
lined in the design method for saltwater sediments.
Refer to Appendix C for an example problem.

b. Step 2. Compute detention time required for sedimentation:

(1) Calculate the removal percentage at depths of 1, 2,
and 3 ft for various times using the plot illustrated
in Figure 9. The removal percentage for depth d_1
and t equals 1 is computed as follows:

$$R = \frac{\text{Area } 0, 10, 11, 1^*}{\text{Area } 0, 2, 11, 1} \times 100 \qquad (5)$$

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* These numbers correspond to the numbers used in Figure 9 to indicate
the area boundaries for the total area down to depth d (0, 2, 11, 1)
and the area to the right of the t-equals-1 time line (0, 10, 11, 1).

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where R is the removal percentage. Determine these areas by either planimetering the plot or by direct graphical measurements and calculations.

This approach is used to calculate removal percentages for each depth as a function of time. The depths used should cover the range of ponding depths expected in the containment area. This report recommends 2 ft of ponding depth. Example calculations are shown in Appendix C.

(2) Plot the solids removal percentages versus time as shown in Figure C3.

(3) Theoretical detention times can be selected from Figure C3 for various solids removal percentages. Select the detention time T that gives the desired removal percentage for the design ponding depth.

(4) The theoretical detention time T should be increased by a factor of 2.25 to compensate for the fact that containment areas, because of inefficiencies, have average detention times less than volumetric detention times:

$$T_d = 2.25T \qquad (6)$$

where T_d is the design detention time.

Volume Requirements for Containment of Solids

64. The procedures outlined in the above paragraphs are aimed at providing containment areas with sufficient areas and detention times to accommodate continuous disposal activities while providing sufficient suspended solids removal to meet effluent suspended solids requirements. Containment areas must also be designed to meet volume requirements for a particular disposal activity. The total volume required of a containment area includes volume for storage of dredged material, volume for sedimentation (ponding depths), and freeboard volume (volume above water surface). Volume required for storage of the coarse-grained (>No. 40 sieve) material must be determined separately as this material behaves independently of the fine-grained (<No. 40 sieve) material.

65. The volume computed in the following steps is the volume occupied by dredged material in the containment area after the completion

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of a particular disposal activity. The volume is not an estimate of the long-term needs for multiple-disposal activities. Estimates for long-term storage capacity can be made using the procedures outlined in Part V. The procedures given below can be used to design for volume required for one disposal activity or used to evaluate the adequacy of volume provided by an existing containment area.

a. Compute the average void ratio of the fine-grained dredged material in the containment area at the completion of the dredging operation using the design concentration determined in earlier steps as the dry density of solids. (Note that the design concentration is determined for both the flocculent and the zone settling design procedures.) Use the following equation to determine the void ratio:

$$e_o = \frac{G_s \gamma_w}{\gamma_d} - 1 \tag{7}$$

where

e_o = average void ratio of the dredged material in the containment area at the completion of the dredging operation

γ_w = density of water, g/ℓ

γ_d = dry density of solids, g/ℓ $(C_d = \gamma_d)$

b. Compute the change in volume of the fine-grained channel sediments after disposal in the containment area:

$$\Delta V = V_i \frac{e_o - e_i}{1 + e_i} \tag{8}$$

where

ΔV = change in volume of the fine-grained channel sediments after disposal in the containment area, ft^3

e_i = average void ratio of the in situ channel sediments

V_i = volume of the fine-grained channel sediments, ft^3

c. Compute the volume required by the dredged material in the containment area

$$V = V_i + \Delta V + V_{sd} \tag{9}$$

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where

V = volume of the dredged material in the containment area at the end of the dredging operation, ft^3

V_{sd} = volume of sand (compute using 1:1 ratio), ft^3

Estimating Depth of the Containment Area

66. Previous calculations have provided a design area A_d and design detention time T_d required for fine-grained dredged material sedimentation. Equations 7, 8, and 9 are used to estimate volume requirements for the containment area. These volumes are then used, as described in the following paragraphs, to determine the corresponding depth requirements. Throughout the design process, the existing topography of the containment area must be considered since it can have a significant effect on the average depth of the containment area.

Saltwater sediments (zone settling)

67. The following procedure should be used for saltwater sediments:

 a. Estimate the thickness of the dredged material at the end of the disposal operation:

$$H_{dm} = \frac{V}{A_d} \qquad (10)$$

where

H_{dm} = thickness of the dredged material layer at the end of the dredging operation, ft

V = volume of dredged material in the basin, ft^3 (from Equation 9)

A_d = design surface area, ft^2 (as determined from Equation 4 or use the known surface area for existing sites)

 b. Consult with soils design engineers to determine the maximum height allowed for confining dikes.[2] Anticipated settlement of the dikes should also be considered.

c. Add the ponding depth and freeboard depth to H_{dm} to determine the required containment area depth (dike height):

$$D = H_{dm} + H_{pd} + H_{fb} \qquad (11)$$

where

D = dike height, ft

H_{pd} = average ponding depth, ft (a minimum of 2 ft is recommended)

H_{fb} = freeboard above the basin water surface to prevent wave overtopping and subsequent damage to confining earth dikes, ft (a minimum of 2 ft is recommended)

d. Compare this value with the allowable dike height (see paragraph 69).

Freshwater sediments (flocculent settling)

68. The following procedure should be used for freshwater sediments:

a. Compute the volume required for sedimentation:

$$V_B = Q_i T_d \qquad (12)$$

where V_B is the containment area volume in cubic feet required for meeting suspended solids effluent requirements.

b. Consult with soils design engineers to determine the maximum height D allowed for confining dikes. In some cases, it might be desirable to use less than the maximum allowed dike height.

c. Compute the design area as the minimum required surface area for storage:

$$A_d = \frac{V}{H_{dm(max)}} \qquad (13)$$

where

$$H_{dm(max)} = D - H_{pd} - H_{fb} \qquad (14)$$

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or set the design area A_d equal to the known surface area for existing sites.

d. Evaluate the volume available for sedimentation near the end of the disposal operation:

$$V^* = H_{pd}A_d \qquad (15)$$

where V^* is the volume in cubic feet available for sedimentation near the end of the disposal operation.

e. Compare V^* and V_B . If the volume required for sedimentation is larger than V^* , the containment area will not meet the suspended solids effluent requirements for the entire disposal operation. The following three measures can be considered to ensure that effluent requirements are met: (1) increase the design area A_d , (2) operate the dredge on an intermittent basis when V^* becomes less than V_B or use a smaller size dredge, and (3) provide for posttreatment of the effluent to remove solids.

f. Estimate the thickness of dredged material at the end of the disposal operation using Equation 10. A_d is determined using step c above.

g. Determine the required containment area depth using Equation 11.

h. Compare this depth with the maximum allowable dike height (see paragraph 69).

69. At most containment areas, the foundation soils are soft. Such foundations limit the heights of confining earth dikes that can be economically constructed. Therefore, soils design engineers must be consulted to determine the maximum dike heights that can be constructed. If the maximum dike height allowed by foundation conditions is less than the containment area depth requirement determined from Equation 11, the design area A_d must be increased until the depth requirement can be accommodated by the allowable dike height; the thickness of the dredged material layer must also be decreased.

Factors Influencing Containment Area Efficiency

70. The design guidelines presented in the preceding sections were developed on the basis of laboratory data. Although these data provide

a basis for the design of full-scale, continuous dredging operations, they must be modified to consider actual performance characteristics of dredged material containment areas. A correction factor of 2.25 was applied to the designs presented earlier to account for the "nonideal" behavior of the full-scale containment area (i.e., scale-up and operation problems). This factor was based on dye tracer investigations performed at active containment areas with physical characteristics similar to the containment area shown in Figure 1.[8,9] From these studies, a correction factor of 2.25 applied to area and detention time requirements appears reasonable. However, this factor can be increased or decreased by the designer if data are available to justify a different correction factor.

71. Short-circuiting is by far the most common and significant fault with dredged material containment areas. The overall effect of short-circuiting is to reduce the effective residence time of a major portion of the flow. This has a serious adverse effect, particularly on sedimentation of freshwater dredged material because of its flocculent nature. Short-circuiting can be caused by insufficient ponding depth, improper location of the dredged material inlet pipeline in relationship to the discharge weir, topography, or vegetation in the basin. All of these cause an improper distribution of velocity vectors resulting in shortened detention periods and increased velocities with resultant scouring of settled solids.

Short-circuiting

72. Ponding depth. Ponding depth is illustrated in Figure 1. Essentially, it is the depth of ponded water above the solids interface required for sedimentation in a containment area. Insufficient ponding depth is a major cause of short-circuiting. Basically, ponding depths should be as great as possible to provide longer detention times, minimize flow velocities, and maximize protection against resuspension and discharge of bottom sediments. Figure 10 is a photograph of a containment area experiencing short-circuiting as a result of insufficient ponding depth. The inefficient flow patterns in this containment area significantly reduce the effective sedimentation area and detention
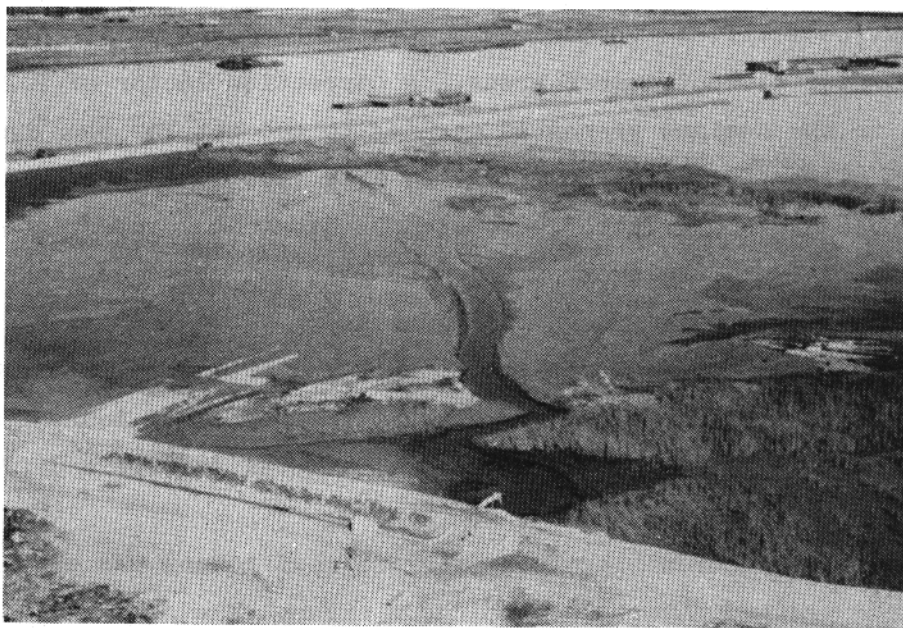
Figure 10. Containment area with insufficient ponding depth
and resultant short-circuiting (from Montgomery[8])
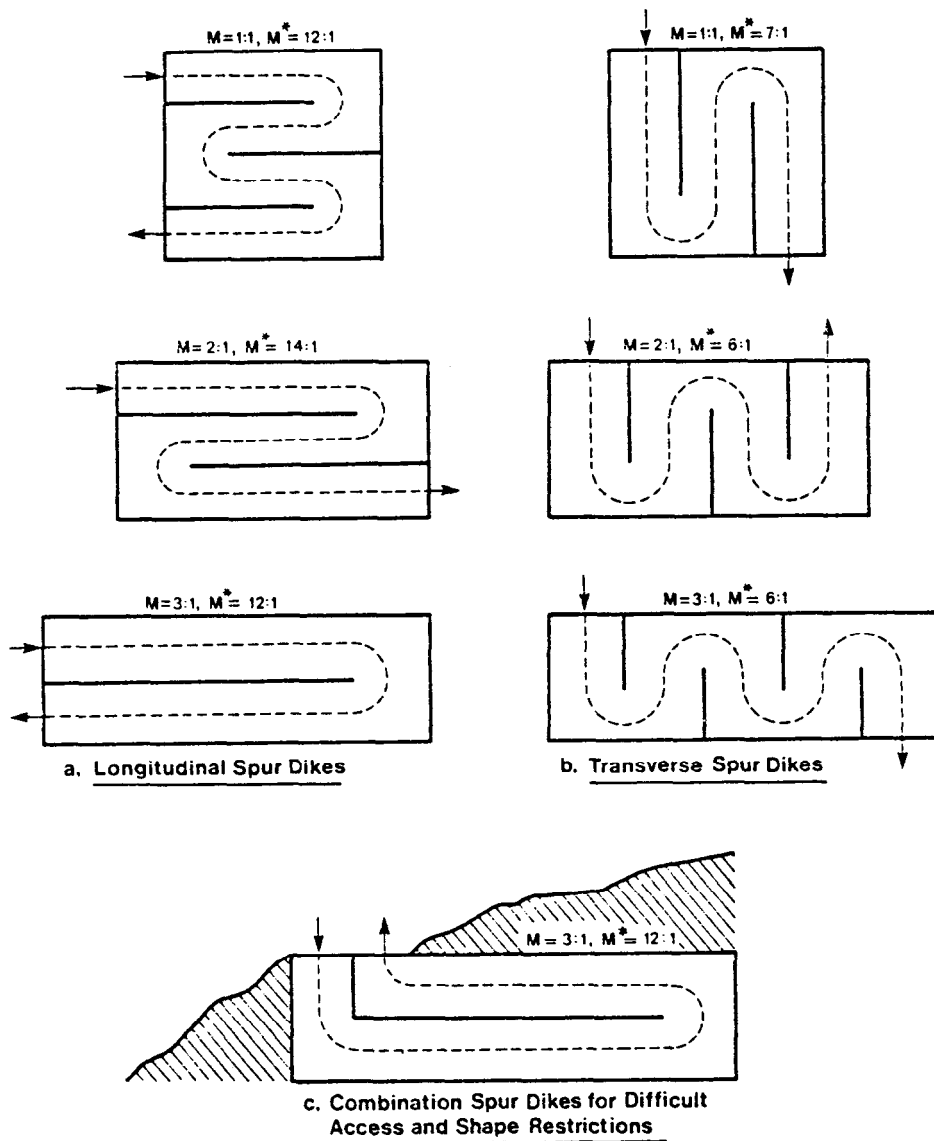
time needed for removal of suspended solids.

73. There has been reluctance in the past to pond water during disposal activities because of concern about potential dike failures. This concern is eliminated when the dikes are properly designed and constructed.[2]

74. Providing adequate ponding depth during disposal activities is an operational as well as a design function. Proper designs can be negated by improper containment area operation such as maintaining insufficient ponding depth. A minimum ponding depth of 2 ft is recommended for sedimentation of solids during a continuous disposal activity. Lesser ponding depths can be tolerated when the dredge is operated on an intermittent basis. Ponding depths greater than 2 ft may be required for efficient weir operation. Refer to Part VI for guidance on weir design and operation.

75. Spur dikes. Spur dikes can be used to minimize short-circuiting and improve dredged material containment area efficiency.[9] In many cases, spur dikes are an economical method for modifying containment areas to provide efficient flow patterns, increase effective

length-to-width ratios, minimize prevailing wind effects, and/or prevent short-circuiting when the inlet and weir must be located on the same side of the containment area.

76. Examples of longitudinal and transverse spur dike configurations are shown in Figure 11. No definite guidelines are available for

a. Longitudinal Spur Dikes

b. Transverse Spur Dikes

c. Combination Spur Dikes for Difficult Access and Shape Restrictions

M=LENGTH-TO-WIDTH RATIO WITHOUT SPUR DIKES
M* =LENGTH-TO-WIDTH RATIO WITH SPUR DIKES

Figure 11. Examples of longitudinal and transverse spur dike configurations (from B. J. Gallagher and Co.[9])

placement of spur dikes. The primary objective is to increase the
length-to-width ratio of the containment area. The following general
guidance is presented for design of spur dikes for a containment area.

  a. One or two spur dikes should usually be sufficient.

  b. The length of spur dikes should be about three fourths
      the length of the parallel side of the containment area.
      Spur dikes longer than this may result in excessive flow
      concentration and increased velocities through the
      spur dike openings.

  c. Spur dikes should not be located close to the outlet
      weir. Spur dikes too close to weirs produce higher
      velocities and may resuspend material in the vicinity of
      the weir.

  d. The additional cost of spur dikes and the loss of surface
      area and containment volume caused by their presence must
      be considered in their design.

  e. The cost of spur dikes can be offset by reducing the
      correction factor used in computing design areas and de-
      tention times. Use of spur dikes would allow smaller
      areas to be used.

  f. In general, the most effective types of spur dikes are
      longitudinal ones parallel to the long side of the con-
      tainment area.

  g. The cost of constructing a spur dike (per lineal foot)
      will usually be considerably less than the cost for con-
      structing the main perimeter dike, due to proportionally
      less material required.

  h. The use of spur dikes in existing containment areas
      could be very helpful in increasing low efficiencies
      resulting from poor design and/or wind effects.

77. DMRP research indicates that the use of a few spur dikes de-
creases dispersion and increases detention time substantially.[9] Model
studies were performed on a containment area 3000 by 1500 ft with a flow
of 70 ft^3/sec and a depth of 5 ft. The following are the results:

No. Spur Dikes	Hours	Detention Time % Increase
0	31	--
1	41.5	34
3	45	45

The dispersion curve was sharpened by the addition of three spur dikes to more closely resemble plug flow.

78. _Weir placement._ Short-circuiting and dead zones can be reduced by the judicious placement of weirs. The shaded area in Figure 12a
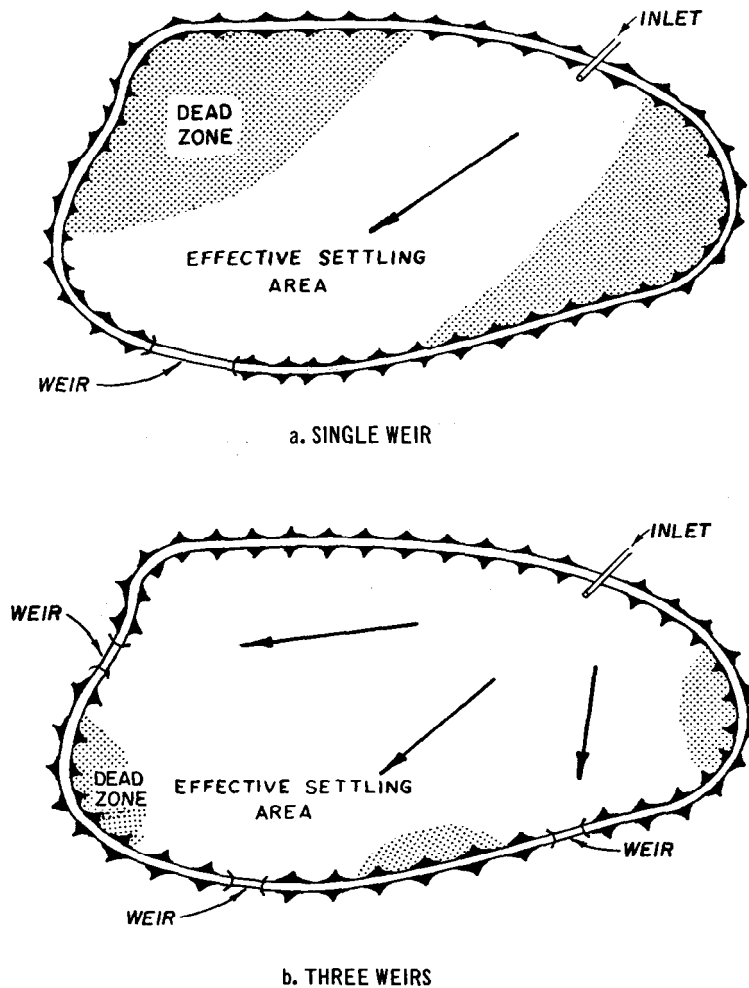

a. SINGLE WEIR

b. THREE WEIRS

Figure 12. Effect of weir location on short-circuiting
(from Walski and Schroeder[19])

indicates dead zones caused by use of one weir. By use of three weirs (each with length one third that of the weir in Figure 12a) the dead zones may be reduced (as shown in Figure 12b). Weir locations should always be selected as far as practicable from anticipated locations of the inlet pipe to increase effective detention time. The following guidelines for location of weirs and inlets are recommended:

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   a. A weir structure(s) should be located at low spots on the perimeter of the containment area as near as practical to the body of water to which effluent is to be discharged.

   b. After the weir location has been specified, the inlet pipe(s) should be located on the perimeter as far from the weir(s) as possible, while being located as near as possible to the dredge to reduce pumping distance.

   c. The inlet pipe(s) should be extended into the containment area far enough to ensure that the slurry cannot flow near the toe of the dikes and cause erosion that could result in dike failure.

79. _Vegetation._ Trees and heavy brush located in containment areas can result in short-circuiting of flow as illustrated in Figure 13.
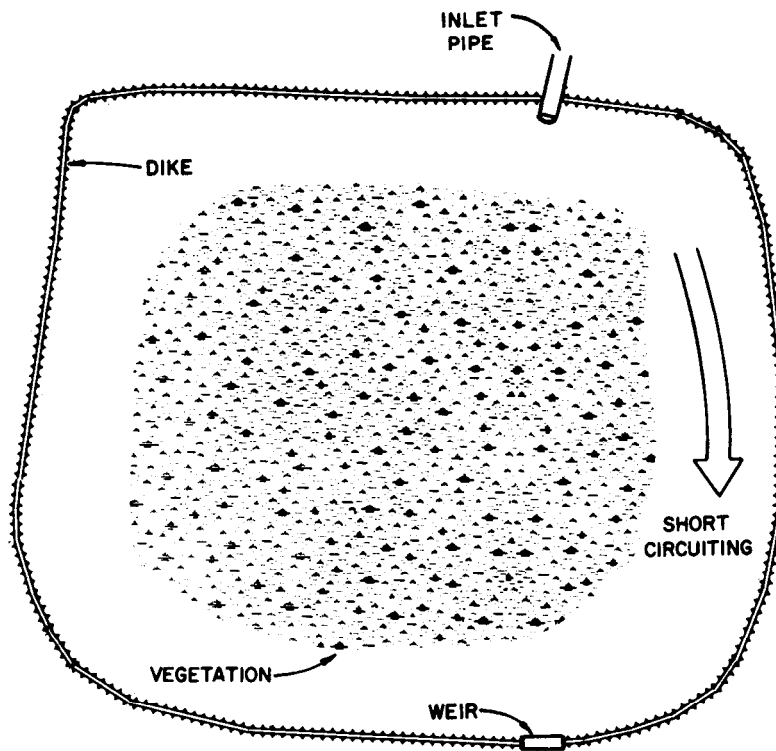

Figure 13. Short-circuiting caused by vegetation in
containment area (from Walski and Schroeder[19])

Serious short-circuiting problems were observed at several active containment areas during research for the DMRP.[19] Vegetation such as weeds and grasses may or may not be beneficial in containment areas. In some cases, such vegetation may act as a filter to improve effluent quality.

However, if the vegetation is too dense, it may cause short-circuiting and/or unwanted buildup of solids near the discharge pipe.

Shape of containment area

80. In practice, economic constraints and land use patterns generally govern the geometry of the land that can be acquired for use as a dredged material containment area. The shape of the containment area should be such that the enclosed volume is effectively used for sedimentation purposes. Economic considerations promote large square-shaped containment areas or areas with low length-to-width ratios. However, the hydraulic efficiencies of these containment areas are low unless modified by internal spur dikes. Containment areas with higher length-to-width ratios are more efficient than square- or irregular-shaped areas but cost more to construct.

81. The following recommendations are made for designing the shape of dredged material containment areas.

    <u>a</u>.   <u>Site selection:</u>

        (1) For design purposes, evaluate the shape and location of the proposed containment area on the basis of economics and efficiency for sedimentation.

        (2) Square-shaped areas should be considered first. Use spur dikes to increase the efficiency for sedimentation.

        (3) Long, narrow strips of land parallel to waterways and near the dredging activity should be the next choice.

    <u>b</u>.   <u>Shape and internal configuration:</u>

        (1) Design the containment area with a high length-to-width ratio (≥ 4).

        (2) If economic factors control, resulting in a large square-shaped containment area, use spur dikes to increase the length-to-width ratio.

        (3) If economic factors do not control and sufficient land is available, design the containment area in the shape of a rectangle with a length-to-width ratio equal to or greater than 4.